DOI: https://doi.org/10.5564/mjas.v27i02.1281

Suitability assessment for siting water harvesting ponds (Case of Erdenetsagaan soum, Sukhbaatar aimag)

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ABSTRACT

This paper represents test results of methodology for identifying suitable sites for the water harvesting pond using the "Multi-Criteria Analysis" in Geographical Information System. In order to do this, the objectives of the identification of harvesting sites were (i)to estimate constraint map (ii) to identify the multi-factor map and (iii) to measure the overall value of the suitability. According to the results of the assessment of the water harvesting suitability, 10.23%or 173736 hectares area of Erdenetsagaan soum of Sukhbaatar aimag(province) are suitable, and 22.71% or 385534 ha area is moderately suitable, and 33.29%or 565198 ha land is limited for pond construction and 33.78% or 573532 ha territory is unsuitable for water harvesting.

KEYWORD: Multi-Criteria Decision Analysis (MCDA), Suitability Analysis, Analytic Hierarchy Process (AHP), Pond site selection

INTRODUCTION

One of the most widely used Geographical Information System (GIS) application on land use planning and land management is the analysis of land-use suitability [1, 2, 3]. In general, assessing the land-use suitability for land-use planning is how thefuture land uses compare according to the most favorable spatial condition or a specific character of land [3]. Consequently, GIS-based land suitability assessment has been widely used in recent years [4,5]. In our country, the assessment of land-use suitability is at the start of the stage or in the process of emerging methodological development.

Global climate change is severely influencing the Mongolian environment and causing ecological imbalance, desertification, water scarcity, vegetation changes and soil degradation appearing everywhere in the region. Especially, land surface temperature increases triggering droughts to rising every year and sudden flood events have a significant negative impact on land degradation and land use. There fore, there is a need to harvest snow and rain waters in areas where surface water sources are not available. It is necessary for nomadic livestock and water supply for the population, as well as for farming, natural rehabilitation, and tourism. Mongolians traditionally used water harvesting measurement and site selection knowledge of ponds and water reservoir have been preserved from ancient times. We have done this research to increase the methodology to be designed more clear and scientifically based on previous international expert's study.

The methodology of the Agency of Land Affairs, Geodesy and Cartography (ALAGaC) for water harvesting in pasture and crop areas is the first significant method and useful guidelines for the site selection of ponds [6]. However, there is a need to improve the above-mentioned methodologyto improve the accuracy and confidence level.Therefore, this study was undertaken to test the methodology "GIS with Multi-Criteria Analysis" in the case of the Erdenetsagaan soum, Sukhbaatar aimag (province) [7] for a suitable site selection of ponds for the agriculture water harvesting. To achieve this, the following objectives have been proposed: (i) assessing the constraints for suitable sites of ponds; (ii) Assessment of suitable sites with the evaluation of multiple factors; (iii) Develop a final assessment of land suitabilityfor water harvesting pond.In order to process the evaluation of multiple factors, we have applied the AHP method [8,9].

METHODS

Research area

Erdenetsagaan soum is located in Sukhbaatar province in the eastern part of Mongolia. The distance between soum center and the capital city of Ulaanbaatar is 768 km. It borders to the west Dariganga soum, to the north-west Asgat and Sukhbaatar soums of the aimag itself, to the north Matad soum of Dornod aimag, and the east and south Shiliingolleague of Inner Mongolia (Figure 1).

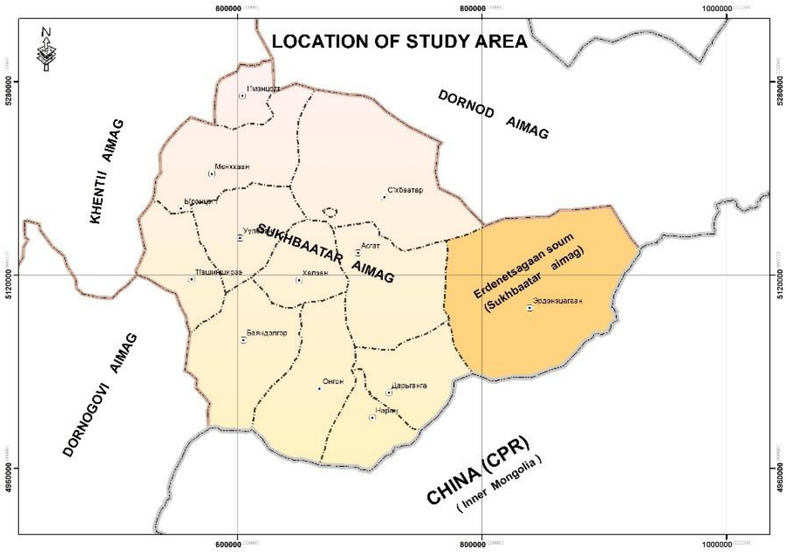

Figure 1. The geographical location of Erdenetsagaan soum
Source: Myagmarjav et al., 2018

Erdenetsagaan soum has a total territory of 1698200.87 hectares and it hasa total of 8 baghs (brigades), which are Jargalant,Khadiin Bulag, Badrakh, Khundlun Khailaast and Tal Bulag in the countryside, 3 baghs in soum center: Tsagaan Ovoo, Biluut, and Altan Ovoo. As of 2016, there are 1634 herder families of 776 households and over 850 seasonal campsites in the territory of the soum. There are 852 sites of pasture had been used by herders, which are 192 winter campsites, 171 spring camp sites, 158 winter and spring camp sites, 295 summer camp sites and 19 pasture lands used whole four seasons.For pasture use, it's observed that the traditional nomadic patterns have been lost in recent years. Nowadays, numbers of semi-nomadic herders have been increased, due to the pasture scarcity and herders are living in a single site for a whole year-round, and all seasonal campsites have been placed in one location.

Multi-criteria analysis

Multi-criteria decision analysisis based on GIS technology [10]. The research has two phases: GIS data layer preparation and constraints and factors assessment. The study was based on geographical information technology (GIT) and multi-criteria analysis (MCA) methods. Constraint maps describing minimum requirements for the site selection and factor maps using weighting factors (calculated from The Analytical Hierarchy Process (AHP) software) are produced using developed criterion and constraint[11]. Then a multi-criteria analysis is performed to identify the suitability of land for water harvesting. Multi-criteria decision analysis is a decision-making tool that uses qualitative or quantitative criterions. One of the most common methods of MCDA based on GIS is AHP. The advantage of this method is that the value of each criterion is rankedstraightforwardlyand the pairwise weight comparison makes it easier. When determining multiple criteria, comparative importance for each criterion of the assessment is weighted by the decision-maker [4,11,12].The necessary data layers for the study area were derived from various sources including a land cover classification map, soil survey archive data, land use planning data [13], satellite data of Landsat 7 image, GDEM 30m- ASTER Global Digital Elevation Model [14]and Land classification digital map,census data[13].

In order to derive values for criteria weights, we used the AHP as the weight solicitation technique [9,15] to check that the scale of weights is valid; we evaluated the weights with a method developed by Brandt [8]. Pairwise comparison is a way of weighting the different factors in correct relation to each other (Eq.1). We are used a weighted linear combination of factors:

$$S = \sum_{i=1}^{n} w_i x_i \quad (1)$$

Where S = suitability to the objective being considered
w_i = weight of factor i [the sum of all weights equal 1]
x_i= criteria score of factor i

Boolean logical overlay method was developed for the constraint combination. The combined constraint map and the combined factor map were multiplied together [16, 17]. The general equation (Eq.2) is:

$$S = \sum_{i=1}^{n} w_i F_i \prod_{j=1}^{m} C_j \quad (2)$$

Where S is the total suitability score, w_i is the weight corresponding to factor map i, and C_j is constraint map j.

Accuracy statistic

The error matrix can provide a variety of measures for accuracy statistics. The most accepted among all measures are overall accuracy: the percentage of correctly matched points with the percentage of misclassified (omitted) points [3,18].The overall accuracy measure assesseshow many points are correctly classified with regards to the reference data which are used as ground truth, dividing it by the total number of points.

We have used the measure of an accuracy that may be derived from an error matrix is the Cohen's kappa coefficient of agreement or the Kstatistics (Eq.3), which gives a guide to the chance of an agreement between assessment map and the reference data [3,18,19].

$$\text{Kappa coefficient} = \frac{n\sum_{i=1}^{q} n_{ii} - \sum_{i=1}^{q} n_{i+}\, n_{+i}}{n^2 - \sum_{i=1}^{q} n_{i+}\, n_{+i}} \quad (3)$$

RESULTS

Constraints are restraint criteria, which means certain areas presenting suitable site and the rest of the place is unsuitable for water harvest pond location. The constraint map was taken into account in terms of existing urban areas, farms, roads, mining areas, lakes, springs, wells, water sources, etc. The Erdas Imagine program had been used for the image processing of each of the selected constraints of the site selection and to create an image and overlap the images.

Table 1

Constraints of site selection of harvesting pond

	Constraint	Value	Consideration
1	Cropland	0	Can not be on the current cropland
2	Current settlement	0	Can not be in the current settlement area
3	Road	0	Do not overlap with roads
4	Mining area	0	Must not be in mining area
5	Lake	0	It is not necessary to have regular water
6	Springs, wells and water sources	0	It does not have to be close to the springs, wells or water sources

Source: ALAGaC, 2016

The constraint map is based on the Boolean method.The Boolean methodpresents only two possible values, zero (0) or one (1), or in other words, suitable or unsuitable (Figure 2).

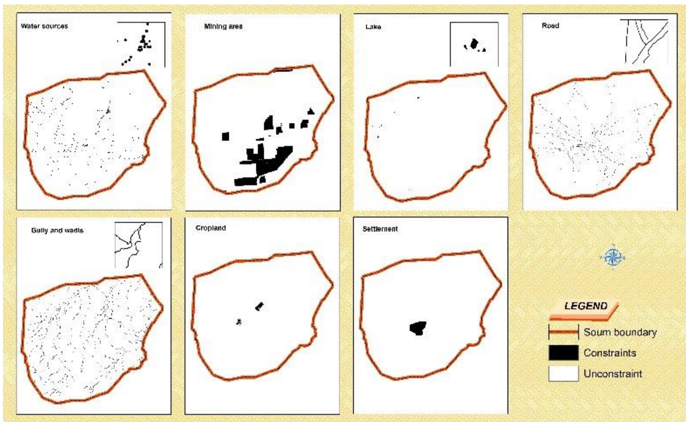

Figure 2. Constraint of the site selection of harvesting pond

The above image is illustrated using the Boolean image conditional value one (1) presented in white color and the value zero (0) is considered inconsistent presented in black color.An image of the whole constraints was summarized in (Figure 2).

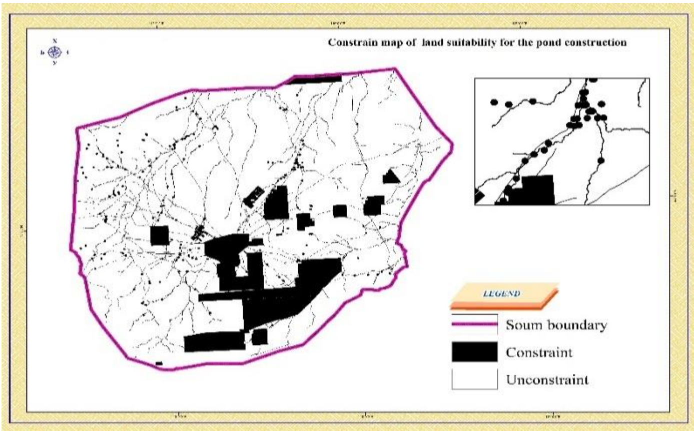

Figure3. Constrain map of land suitability for the pond construction

According to the constraint assessment, 84.4 percent of the total territory of the soum or 1433048 ha is suitable, and 15.6 percent or 264952 ha is unsuitable for pond construction. The multi-criteria analysis method is used when many factors are used in the suitability assessment (Figure 3).Compared to many factors, one is more important than the other, and the weight is weighted for the assessment.The AHP method was used to weight factors [8,9].

Table 2

Ranking and weighing the factors for site selection of pond

	Factor	Rank	Relative weight
1	Precipitation	1	0.3506
2	Land slope	2	0.2375
3	Dry streams, gully and wades	3	0.1589
4	Soil permeability	4	0.1055
5	Herders campsite location	5	0.0696
6	Water source location	6	0.0461
7	The location of the cropland	7	0.0317
	CR=0.035		

The most important of these ranking factors are the precipitation, slope and soil water permeability, and the most unimportant ones are the groundwater level which had been excluded from the assessment.It is assumed that the ratio between the factors is stable with 0.035 consistency value, which corresponds to the value of the weights determined by the AHP method.

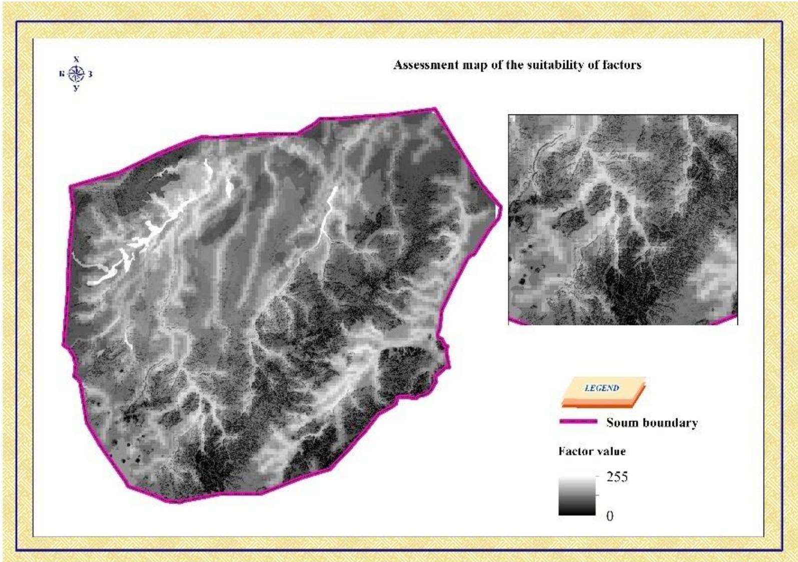

Figure 4. Assessment map of the suitability of factors in the build of the pond

For the analys is of different types of data together, all data need to be converted to the color numerical format. Therefore, to represent the suitability, all factors were normalized, meaning in this case that the value ranges of all factor maps were stretched from 0 to 255 in ERDAS IMAGING software. This means that 0 (black color area) is counted to be low suitability and 255 (white color area)presents high suitability (Figure 4). The higher the values are, the more suitable for the water harvesting ponds.

An integrated image of the constraints and factors of the suitability for the site selection ofponds presented in (Figure5) and (Table 3).

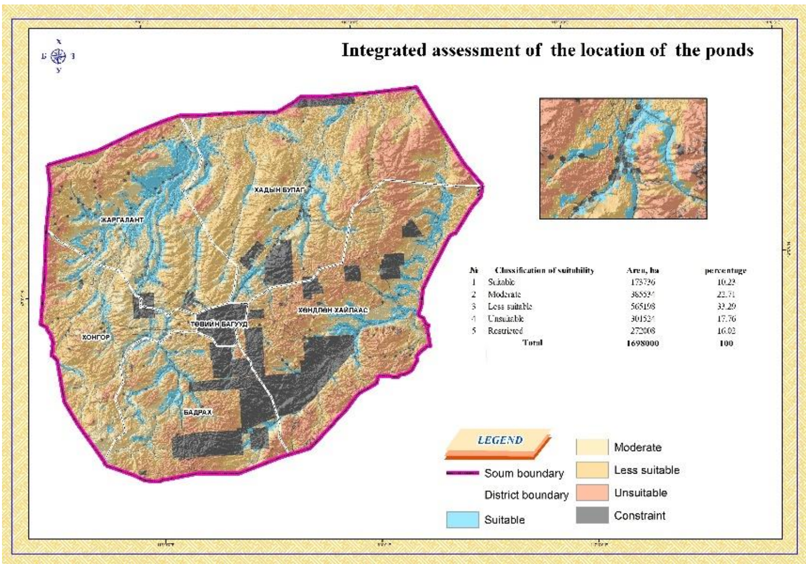

Figure 5. Integrated assessment of the location of the ponds

The integrated assessment of the suitable location of the pond was classified asverysuitable, suitable, moderate,less suitable, unsuitable, and restricted.

Table 3

Integrated assessment of the location of the ponds

	Classification of suitability	Area, ha	Percentage, %
1	Suitable	173736	10.23
2	Moderate	385534	22.71
3	Less suitable	565198	33.29
4	Unsuitable	301524	17.76
5	Restricted	272008	16.02
	Total	**1698000**	**100**

Based on the results of the integrated assessment of the suitability for siting the ponds, 10.23 percent or 173736 hectares of Erdenetsagaan soum of Sukhbaatar aimag are suitable, 22.7 percent or 385534 ha are moderate, 301524 ha is unsuitable, and 16 % or 27,2008 hectares of land is restricted.

DISCUSSION AND CONCLUSION

To check the accuracy and agreement with reference (actual situation in the local area), Kappa agreement statistic had been processed in error matrix where survey result factor map and field study materials of Territorial Development Plan's baseline survey for pasture irrigation are compared [7] as a reference (Figure 6).

Table 4

Error matrix

Classification of suitability	Reference point	Assessment map point	Matched point	Compatibility, %
Unsuitable	49	51	39	76,47
Less suitable	43	38	34	89,47
Moderate	46	50	38	76,00
Suitable	51	50	37	74,00
Overall accuracy			**0.78**	
Kappa coefficient			**0.71**	

It can be concluded that the suitability assessment map is modeled correctly according to the result of overall accuracy 0.78, compatibility 72-95% and Kappa coefficient 0.7. The locations of the suitable land identified after surveys were matched to the current location of the planned area for pasture irrigation.

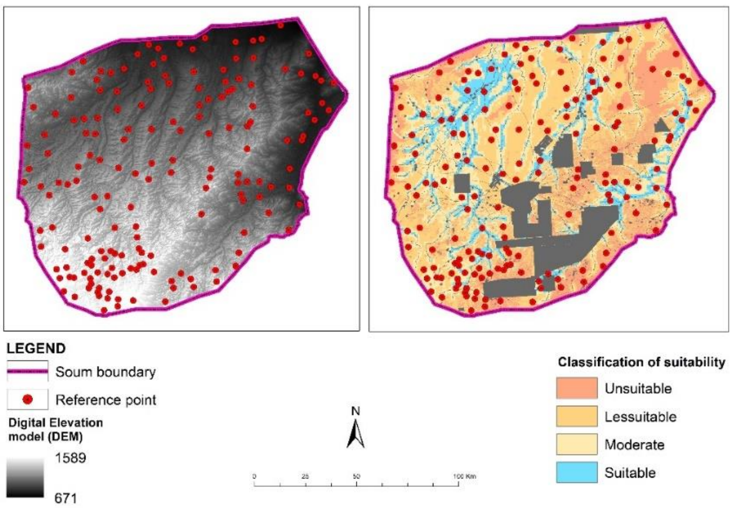

Figure 6. Accuracy assessment reference points

In Mongolia, the traditional methods of site selection of ponds and water reservoirs have beenpreserved from ancient times but are still missing out on a scientific report about.We have done this research to increase the methodology to be designed more clear and the methods of calculation of influencing factors to be accurate. Altansukh et al.[20] developed the same method. In our study, we tried to improve the ideas presented by these scientists adding more criteria [21,22].

Table 5

Proposed criterions

Rank	Criteria	Value	Normalized value
I	Precipitation (mm)	>300	4
		200-300	3
		100-200	2
		<100	1
II	Land slope (%)	<3.0	4
		3-5	3
		5-10	2
		>10	1
III	Distance to wades(m)	<500	4
		500-1000	3
		1000-2000	2
		>2000	1
IV	Soil clay content (%)	>35	4
		18-35	3
		10-18	2
		<10	1
V	Gully density (km^2 / km)	>1	4
		0.75-1.0	3
		0.5-0.75	2
		<0.5	1
VI	Distance to user (e.g, Herders seasonal pasture land, cropland etc)	<2	4
		2-3	3
		3-4	2
		>4	1
VII	Distance from the water source (km)	>5	4
		4-5	3
		3-4	2
		<3	1

Source: Rida etal., 2010; Disyacitta, 2017

Several researchers had been chosen a variety of criterions for site selection of water harvesting. Tambo et al. [23] in Tanzania and Mosase et al. [24] in Botswana are choosing the criterion soil texture, soil depth, soil drainage, topography and land use for water harvesting. Singhai et al. [25] additionally used surface runoff data and lineament (rock cleavages, fault, and fractures affect the groundwater recharge) of groundwater in the Bundelkhand region, India. However, compare with our study most of the researchers used only physical criterions and missed by social and economic factors whereas we are proposing further study methods. In the future, the site selection of the ponds should include geologicalgeomorphological parameters (sediment type, bedrock properties), weather factors (rain intensity, evaporation, etc.)[22]. In our case, we were unable to present Erdenetsagaan soum's detailed information and have not been included in the methodology due to a lack of relevant information used by similar studies from other arid regions which are compared in the paper above mentioned.

ACKNOWLEDGMENT

We would like to express our gratitude to Sukhbaatar aimag's Land Department for their support in carrying out this research.

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